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TITLE OF INVENTION:

AFCI Temperature Compensated Current Sensor

TO WHOM IT MAY CONCERN, THE FOLLOWING IS
A SPECIFICATION OF THE AFORESAID INVENTION

AFCI Temperature Compensated Current Sensor

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Field of Invention

The present invention relates to an apparatus and method for sensing and translating a current signal into a temperature compensated voltage signal used by an Arc Fault Circuit Interrupter (AFCI) detection circuit.

Background

In general, several different types of sensing apparatus have been used to measure current in an electrical circuit. Such sensing apparatus may utilize sense resistors, current transformers, and Hall Effect sensors. These sensors are used to monitor and measure current as it is passes through the load of a circuit either for purposes of overcurrent protection or to control another circuit based on the measured current in the load.

Sensors are also used to detect wave forms and the shape of current which can indicate the presence of an arc fault. Arcing faults may be defined as the existence of a current path between two ends of a broken conductor located within an ionized gas, between two conductors supplying a load, or between a conductor and a ground. Arcing faults are characterized by low and erratic current flow. Arcing faults may be undetected by standard circuit breakers, because the current flow may be below the breaker's tripping threshold. Upon occurrence of an arcing fault, branch or load impedance may cause the current

levels to be reduced to a level below the trip curve setting of the circuit breaker, causing the arcing fault condition to be undetected by a circuit breaker. In addition, an arcing fault which does not contact a grounded conductor or other grounded point will not trip a ground fault protected circuit.

During the current measurement, it is important to maintain galvanic isolation in order to assure that current does not flow directly between the load and the measuring circuit. Sense resistors, typically, are accurate, inexpensive, and provide a higher frequency response than the other two types of sensors mentioned above. However, a disadvantage of the sense resistors is that they provide no galvanic isolation. Another disadvantage is that the sensor output signal tends to vary with temperature variations. This is due to the composition of the sensing material used. Metals have an inherent property of changing resistance when ambient temperatures fluctuate. By way of example, the proportionality of a signal being converted at 25 degrees Celsius will be different from the same signal being converted at 66 degrees Celsius or -35 degrees Celsius. Similarly, the sensitivity of the circuit changes if there is a deviation from a nominal operational temperature of 25 degrees Celsius. Known sense resistor configurations do not compensate the current for this variance in ambient temperature. Therefore, a need exists to compensate for temperature induced signal drift.

On the other hand, both current transformers and Hall Effect sensors provide galvanic isolation. Current transformers also provide proportional signals with suitable accuracy at a wide operational temperature range. However, both

current transformers and Hall Effect sensors are more expensive solutions. Further, the frequency content for current transformer and Hall Effect sensors will be lost or will be filtered out because they have a low pass filter type transfer function. A disadvantage of a low pass filter type transfer function is that the critical information of the frequency content provided at higher frequencies will be missed. A further disadvantage of current transformers is that they occupy a relatively large area of a printed circuit board.

Summary of Invention

It is therefore an object of the present invention to provide an improved sense resistor apparatus for supplying a valid current signal to an arc fault circuit interrupter detection circuit at varying ambient temperatures.

It is also an object of the present invention to provide an improved sense resistor that is inexpensive, accurate, responds at high frequencies, and imparts galvanic isolation at varying ambient temperatures.

In accordance with one aspect of this invention, a temperature compensated current sensor for a circuit protection apparatus comprises:
a circuit protection device for coupling to a powered circuit having current flowing therein; a bus for carrying the power therethrough; a sensing resistor electrically coupled to the bus for sensing current flow through the bus; temperature sensitive compensation circuit coupled to the sense resistor for compensating ambient temperature; and an output for reading the current.

In accordance with another aspect of this invention, a sense resistor apparatus for providing a temperature independent current signal at varying ambient temperatures, comprises: a sense resistor for sensing a current passed through the sense resistor and generating a voltage signal; and at least one thermistor for thermally compensating the voltage signal generated through the sense resistor.

In accordance with another aspect of this invention an apparatus for thermally compensating a voltage signal for an AFCI circuit, comprises: a sense resistor for sensing a current passed through the sense resistor and generating the voltage signal; at least one thermistor for thermally compensating the voltage signal generated through the sense resistor; and an operational amplifier for conditioning a thermally compensated voltage signal before the thermally compensated voltage signal enters a detection circuit of an arc fault circuit interrupter device.

In accordance with another aspect of this invention, a method for translating a current signal into a temperature compensated voltage signal for an AFCI circuit, comprise:generating a voltage signal by passing the current signal through a sense resistor; applying the voltage signal through at least one thermistor to generate a thermally proportional voltage signal; amplifying the thermally proportional voltage signal by energizing an operational amplification circuit; and determining whether a detection circuit of an arc fault circuit interrupter device detects the thermally proportional voltage signal.

In accordance with another aspect of this invention, a method for thermally compensating a voltage signal, comprises generating the voltage signal by passing a current signal through a sense resistor; and applying the voltage signal through at least one thermistor to generate a thermally proportional voltage signal.

In accordance with another aspect of this invention, a method for thermally compensating a current sensor for a circuit protection apparatus comprises coupling a circuit protection device to a powered circuit having current flowing therein; coupling a bus for carrying the power therethrough; electrically coupling a sensing resistor to the bus for sensing current flow through the bus; coupling a temperature sensitive compensation circuit to the sense resistor for compensating ambient temperature; and reading an output of the current.

Brief Description of Drawings

Fig. 1 a) is a side view of the sense resistor incorporated into a powered circuit.

Fig. 1 b) is a perspective view of the sense resistor incorporated into a powered circuit.

Fig. 2 is a schematic circuit diagram of the sense resistor with a Positive Temperature Coefficient (PTC) thermistor configuration

Fig. 3 is a schematic circuit diagram of the sense resistor with a Negative Temperature Coefficient (NTC) thermistor configuration

Fig. 4 is a schematic circuit diagram of the sense resistor with a Positive Temperature Coefficient (PTC) thermistor configuration & Negative Temperature Coefficient (NTC) thermistor configuration

Detailed Description

Figure 1a) refers to the components incorporated in a powered circuit 10 comprising a printed circuit board 100 comprising push to test switches 110, power clip 120, solenoid 130, part of neutral trace 140, differential sensor 150, line terminal 160, sense resistor 170, neutral pigtail 180, neutral lug 185, and contact 190. Power clip 120 connects printed circuit board 100 to a voltage source.

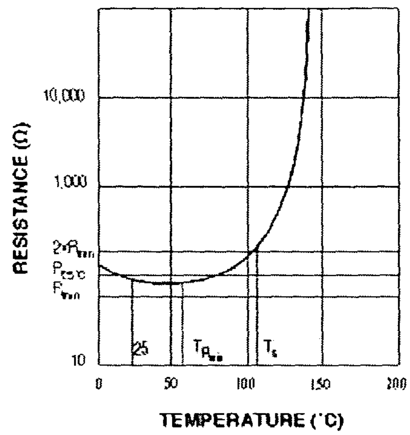
Current is sensed when a proportional voltage signal is generated by the passage of current through the sense resistor 170. By switching on a load, a current is first sent through the partial of neutral trace 140 to the differential sensor 150. The differential sensor 150 is used to detect hot to neutral situational arcs to safeguard ground wire devices. Solenoid 130 comprises a plunger 135 that extends upon reaction and detection of a hot to neutral situational arc by differential sensor 150. From the differential sensor 150, the current flows to the sense resistor 170 and then out through neutral pigtail 180 which is crimped to the neutral boss on a load center to complete the circuit and path of current with load center. The neutral pigtail 180 may also be used to attach a circuit breaker, such as an Application Specific Integrated Circuit (ASIC) detection circuit of an

arc fault interrupter device. The sense resistor 170 is part of the current path of the ASIC detection circuit of an arc fault circuit interrupter device.

Referring to Figs. 1a and 1b in conjunction with Fig 2, first 220 and second 221 Positive Temperature Coefficient (PTC) thermistors are connected to pins 14 and 15, respectively of ASIC detection circuit 240. A PTC thermistor 220 is a thermally sensitive semiconductor resistor that is well known in the art whose primary function is to exhibit a change in electrical resistance with a change in body temperature. One ordinarily skilled in the art may use a PTC thermistor 220 constructed from ceramic materials and linear in nature. A nominal PTC thermistor 220 measures 10 k Ohm of resistance at 25 degrees Celsius. Change in the resistance of a PTC thermistor 220 can be brought about either by a change in the ambient temperature or internally by self heating resulting from current flowing through the device. At room temperature, the resistance of PTC thermistor 220 is almost zero. Sense resistor 170 is connected between the first 220 and second 221 PTC thermistors. Line terminal 160 serves to connect a stab assembly used in the load center to the differential sensor 150.

In accordance with the present invention, the resistance value of the sense resistor is selected such that the voltage generated will be sufficiently large enough to be used by the ASIC detection circuit 240 and small enough to not apply detrimental electric voltage. By way of example, the resistance value may be approximately 250 micro Ohms, although it is understood that other suitable resistance values may be selected.

Referring to Figure 2, the preferred embodiment, the current flows from load neutral 200 through the sense resistor 170 (point 1 to point 2) and then to the neutral pigtail 180 (also considered earth). Voltage is produced as the current flows through the sense resistor 170. This voltage potential is attenuated by the first 220 and the second 221 PTC thermistor. In the case of an overcurrent situation, resistance rises within the first 220 and the second 221 PTC thermistor. This additional resistance in the circuit has the effect of reducing the overall current. Once the overcurrent situation has been removed, the first 220 and the second 221 PTC thermistor will cool, in doing so their internal temperature drops resulting in the resistance returning to a low state. The first 220 and the second 221 PTC thermistor can be formulated to have switching temperatures as low as 0 degrees Celsius to well over 200 Celsius. The ambient temperature will force the first 220 and the second 221 PTC thermistor's resistive properties to change. If the ambient temperatures are above 25 degrees Celsius, then the resistive properties of the first 220 and the second 221 PTC thermistor will increase automatically as the first 220 and the second 221 PTC thermistor are passive electrical devices. Alternatively, if the ambient temperature is below 25 degrees C, then the resistive properties of the first 220 and the second 221 PTC thermistor will decrease to a low state. See chart below.



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- Thermal connections
- Switch temperature (T_S)
- Resistance at 25°C (R_{25})
- Surface area
- Maximum voltage (V_{max})

Therefore, the first 220 and the second 221 PTC thermistor is directly proportional to temperature and has a different resistance value based on different ambient temperatures. The first 220 and the second 221 PTC thermistor dynamically compensates the voltage signal proportion to the changes in resistance of the metal in the first 220 and the second 221 PTC thermistor due to the exposure to ambient temperatures above and below and below 25 degrees Celsius. As the ambient temperature increases, then the resistive properties of the first 220 and the second 221 PTC thermistor will also increase. Also, if the ambient temperature increases, the voltage signal generated from the sense resistor 170 will increase. Prior to the voltage signal entering the ASIC detection

circuit 240 of the AFCI device, the first 220 and the second 221 PTC thermistor will compensate for this change in voltage signal the following way:

$$V_{OUTPUT} = V_{INPUT} \times (R_{FIXED}/R_{PTC})$$

V_{OUTPUT} is the thermally compensated voltage output. R_{PTC} is the resistance of the first 220 and the second 221 PTC thermistor at the specific ambient temperature. R_{FIXED} is the resistance of an off the shelf resistor that has a constant resistance value at a 25 degree Celsius ambient temperature nominally valued at 300 k Ohms. V_{INPUT} is the voltage generated as current passes through the sense resistor 170 at ambient temperatures. The thermally compensated voltage signal is equal to the ratio of the resistance of a first 220 and a second 221 PTC thermistor at 25 degrees Celsius divided by the resistance of a first 220 and a second 221 PTC thermistor at the ambient temperature as applied to the voltage signal generated by the sense resistor 170 at ambient temperatures. Therefore, the change in temperature for the voltage output is linearly inverse to that of the sense resistor 170 in order to mitigate any effects due to temperature change.

Once the voltage signal is attenuated, the output is then passed through an operational amplifier 230 for final conditioning. The operational amplifier 230, located inside the ASIC circuit 240, connects in a negative feedback configuration whereby there is high impedance and therefore negligible current. This negative feedback configuration allows the amplification of the voltage signal. The operational amplifier 230 is powered by 1016 VDC which is a 10 V

DC source feeding the ASIC circuitry 240 and the ASIC circuitry 240 regulates the voltage signal to all the internal components. The output of the operational amplifier 230 is sent back to lead 13. The amplification occurs because the voltage signal coming from the sense resistor 170 is a low voltage value and requires a higher voltage value for detection by the ASIC circuit 240. The ASIC circuit 240 is responsible for detecting the arc. The ASIC circuit 240 is assigned to pick up the particular singularities or features of the current waveform sensed by the sense resistor 170. The only way to observe an arc fault is if there is a current flowing through the powered AC line.

Figures 3 shows another embodiment using one NTC thermistor 250 in contrast to the first 220 and the second 221 PTC thermistor. The NTC thermistor 250 would replace a negative feedback resistor with the condition that the operational amplifier 230 does not saturate. The Negative Temperature Coefficient (NTC) thermistor 250 is a thermistor whose zero-power resistance decreases with an increase in temperature. Therefore, a NTC thermistor 250 is inversely proportional to temperature increase and will compensate the voltage signal as follows:

$$\mathbf{V_{OUTPUT} = V_{INPUT} \ x \ (R_{NTC}/R_{FIXED})}$$

where the value of the thermally compensated voltage signal is equal to the ratio of the resistance of the NTC thermistor 250 at the ambient temperature divided by the resistance of the NTC thermistor 250 at a normal 25 degrees Celsius

ambient temperature applied to the voltage generated through the sense resistor 170. V_{OUTPUT} is the thermally compensated voltage output. R_{NTC} is the resistance of the NTC thermistor at the specific ambient temperature. R_{FIXED} is the resistance of an off the shelf resistor that has a constant resistance value at a 25 degree Celsius ambient temperature. V_{INPUT} is the voltage generated as current passes through the sense resistor 170 at ambient temperatures.

Figure 4 shows another embodiment using the configuration two PTC thermistors 220 and one NTC thermistor 250 simultaneously. In this embodiment, the sense resistor 170 will be able to measure the more dramatic changes in the electrical system due to varying ambient temperatures. There are situations where the first 220 and the second 221 PTC thermistor do not provide adequate compensation for the AC current in the power line and the voltage output of the sense resistor 170 at varying ambient temperatures. In this embodiment, the configuration of the first 220 and the second 221 PTC thermistor and the NTC thermistor 250 in combination with the sense resistor 170 allows for additional compensability.

While the present invention has been disclosed with reference to certain embodiments, numerous modifications, alterations, and changes to the described embodiment are possible without departing from the sphere and scope of the present invention. Accordingly, it is intended that the present invention not be limited to the described embodiments and equivalents thereof.